First Results from the Antarctic Impulsive Transient Antenna Experiment

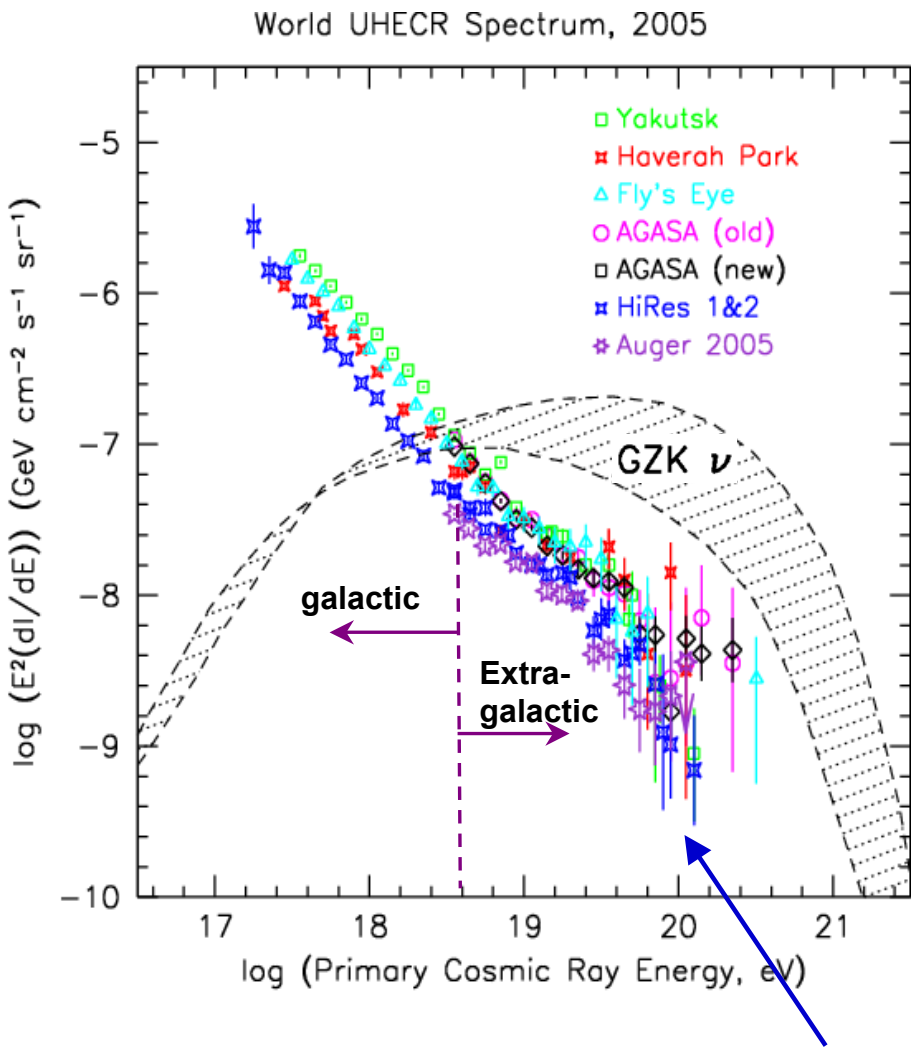
Peter Gorham
University of Hawaii

Outline

- GZK cutoff, & neutrinos
- The Askaryan effect
- Radio Antarctica
- ANITA prototype: ANITA-lite
- Plans & prospects

(Ultra-)High Energy Physics of Cosmic rays & Neutrinos

- Neither origin nor acceleration mechanism known for cosmic rays above 10^{19} eV, **after 40 years!**
- A paradox:
  - No *nearby* sources observed
  - distant sources *excluded* due to GZK process
- **Neutrinos** at $10^{17\text{-}19}$ eV **required** by standard-model physics* through the GZK process--and observing them is crucial to resolving the GZK paradox



* Berezinsky et al. 1971.

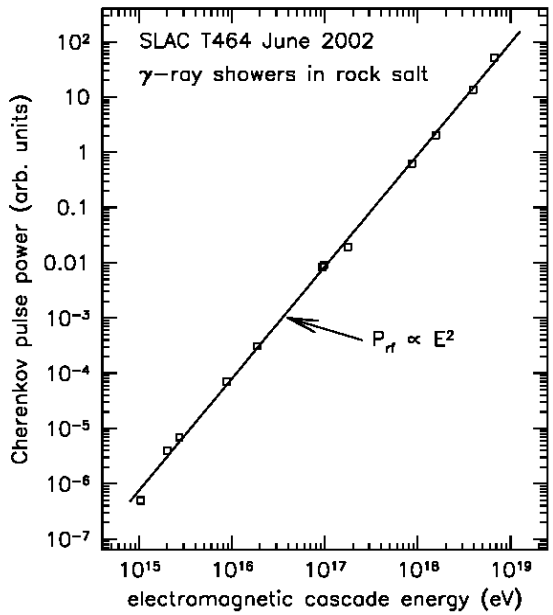
What is needed for a GZK ν detector?

- Standard model GZK ν flux: <1 per km^2 per day over 2π sr
  - Interaction probability per km of water = 0.2%
  - Derived rate of order 0.5 event per year per cubic km of water or ice

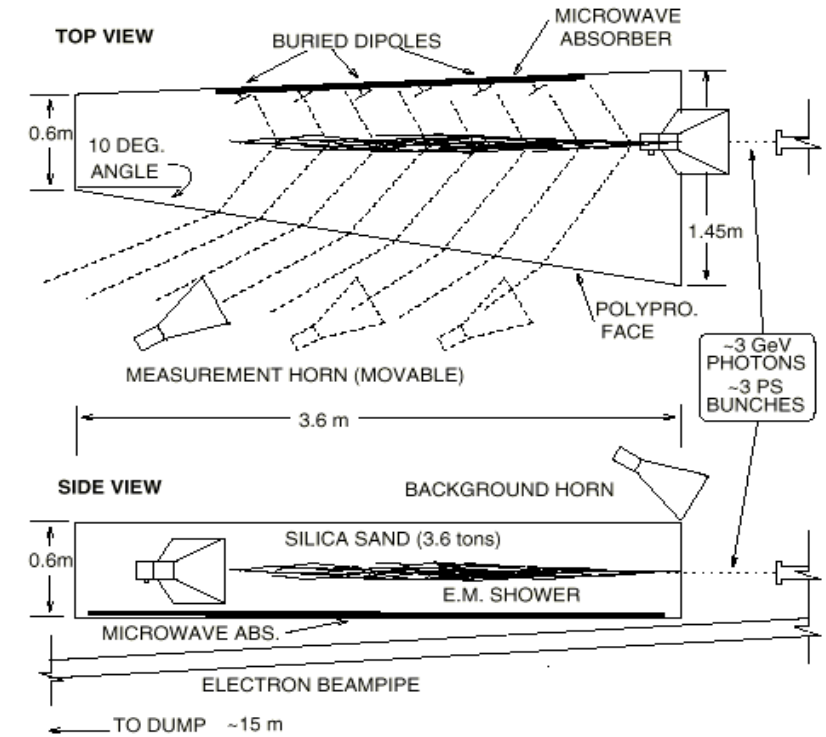
➔ A teraton sr (1000 km^3 sr) target is required!

Problem: how to scale up from current water/ice Cherenkov detectors?

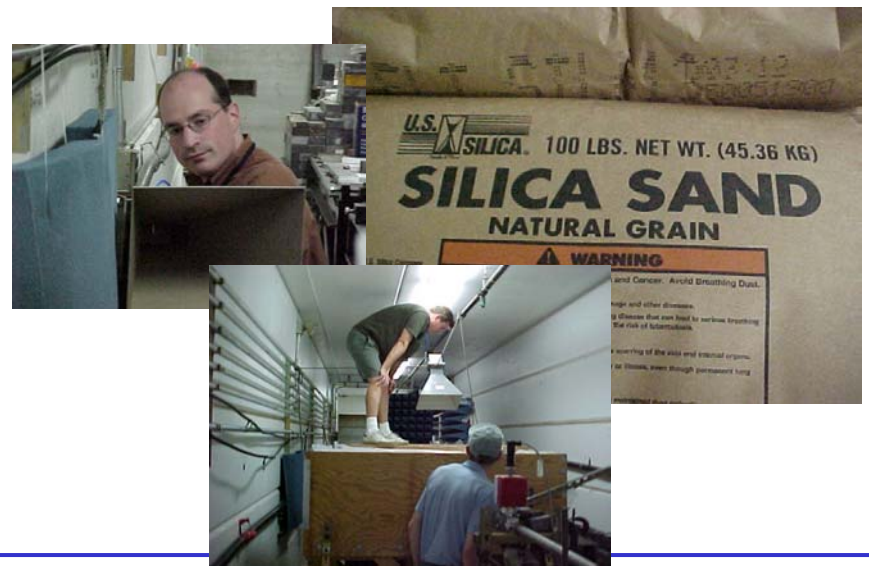
- **One solution: exploit the Askaryan effect: coherent radio Cherenkov emission**
  - Particle showers in solid dielectric media yield strong, coherent radio pulses
  - Neutrinos can shower in many radio-clear media: air, ice, rock-salt, etc.
  - Economy of scale for a radio detector (antenna array + receivers) is very competitive for giant detectors



Askaryan Effect: SLAC T444 (2000)

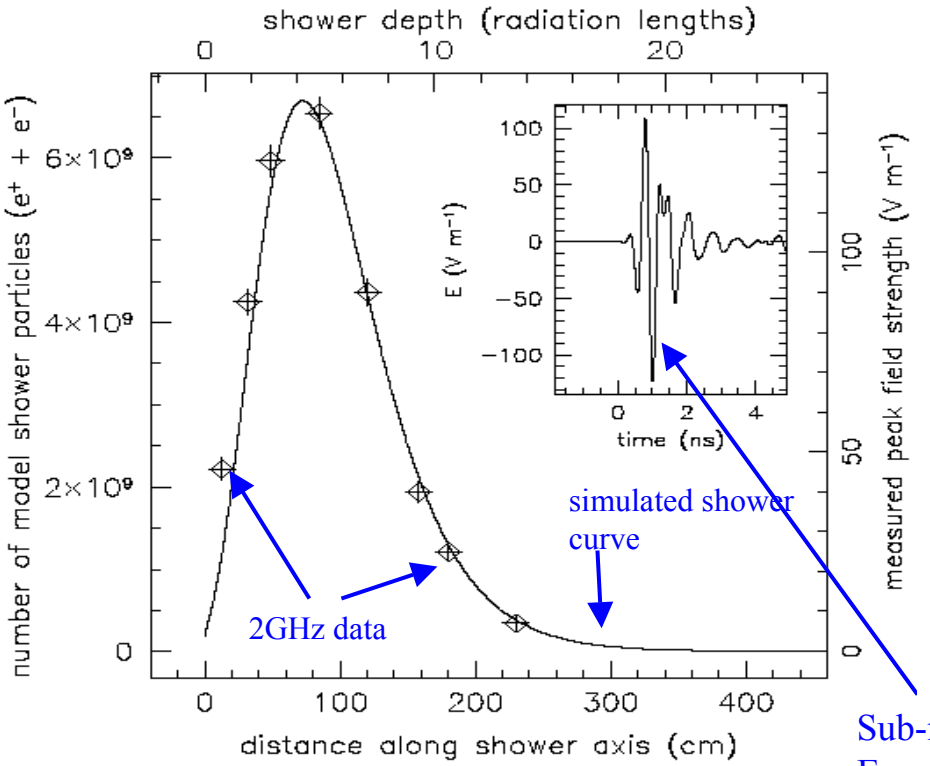


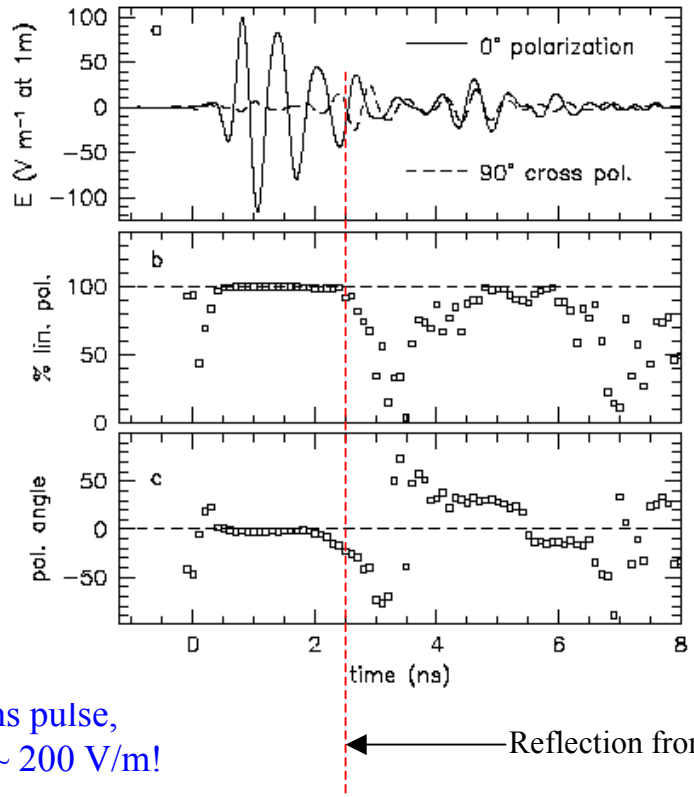
From Saltzberg, Gorham, Walz et al PRL 2001



- Use 3.6 tons of silica sand, brem photons to avoid any charge entering target
  ==> avoid RF transition radiation
- RF backgrounds carefully monitored
  - but signals were much stronger!

Shower profile in microwaves



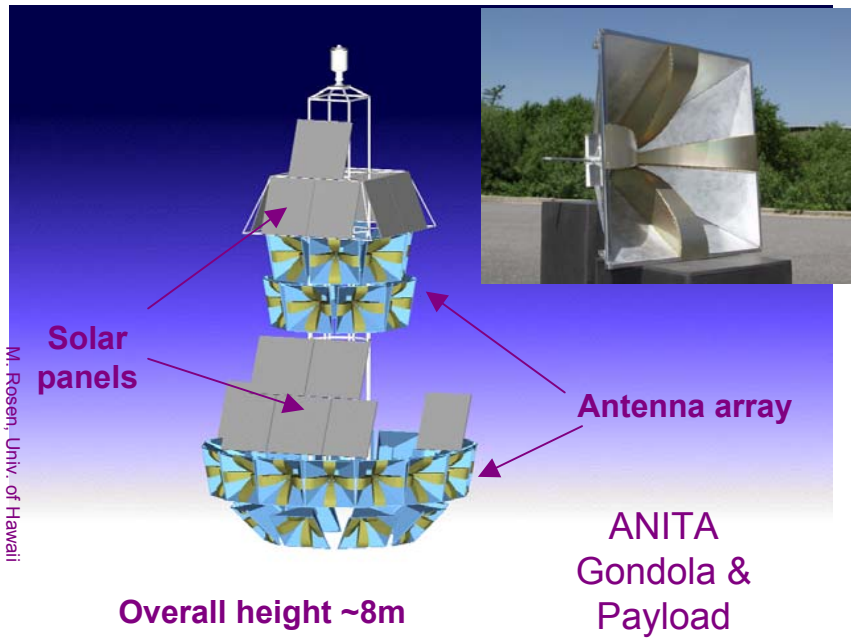


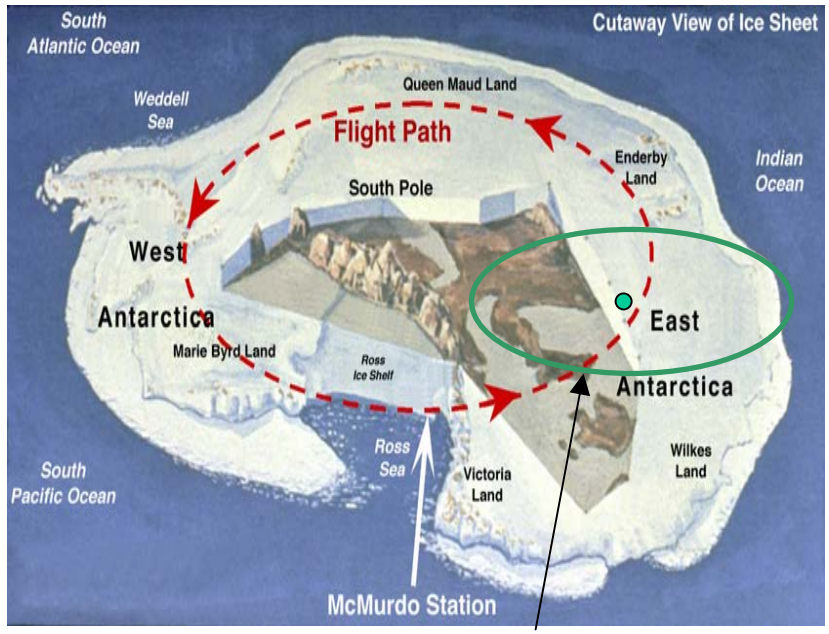
- Measured pulse field strengths follow shower profile very closely
- Charge excess also closely correlated to shower profile (EGS simulation)
- **Polarization** completely consistent with Cherenkov—**can track particle source**

Design for GZK ν flux

- Huge Volume of solid medium: Antarctic Ice
- Broadband antennas & low noise amplifiers to watch it
- A very high vantage point, but not too high or too far away
- The end result: ANITA

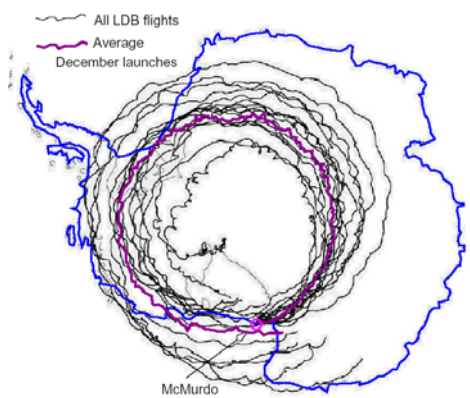
Antarctic Impulsive Transient Antenna





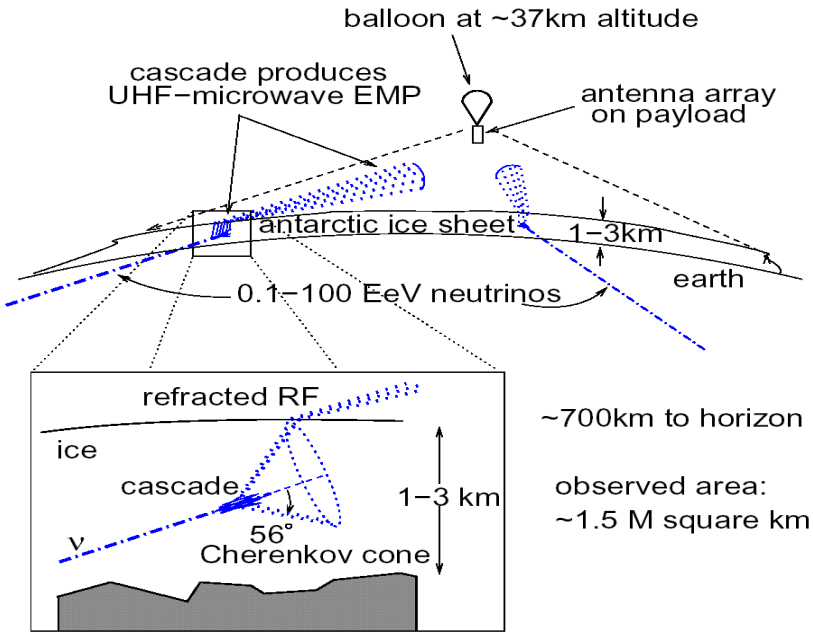
Instantaneous balloon field of view

- NASA SR&T start in 2003
- launch in '06-07, every two years after



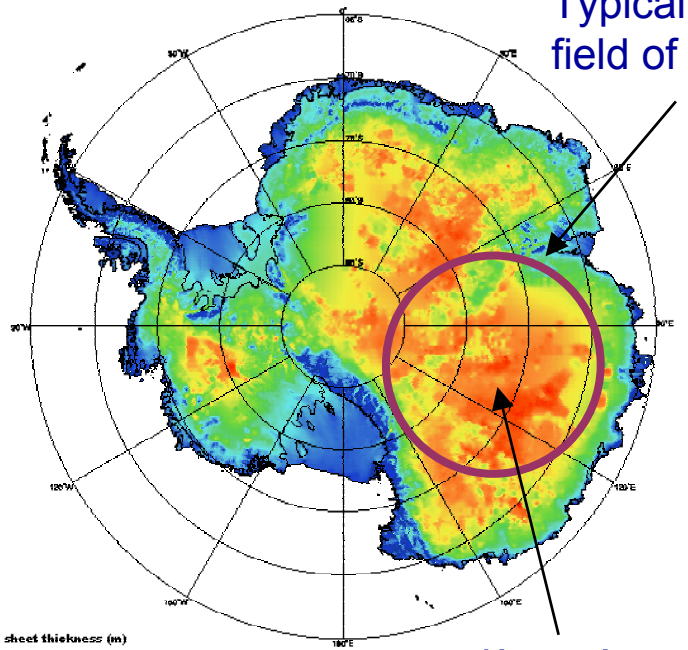
- UH (P. Gorham, C. Hebert, J. Learned, J. Link, S. Matsuno, P. Miocinovic, B. Stokes, G. Varner), UCI (S. Barwick, J. Nam), JPL (K. Liewer, C. Naudet), Ohio State U. (J. Beatty, R. Nichol), U. Del. (D. Seckel, J. Clem), UCLA (D. Saltzberg, A. Connolly), U.Minn. (M. DuVernois), Univ. Kansas (D. Besson)

ANITA concept

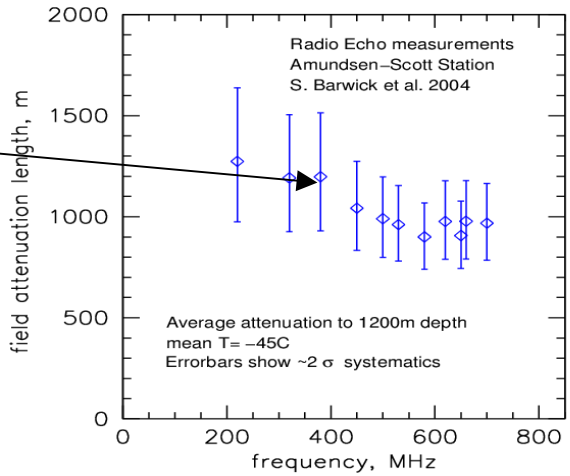


~700km to horizon

observed area:
~1.5 M square km



Ice RF clarity: ~1.2 km(!) attenuation length

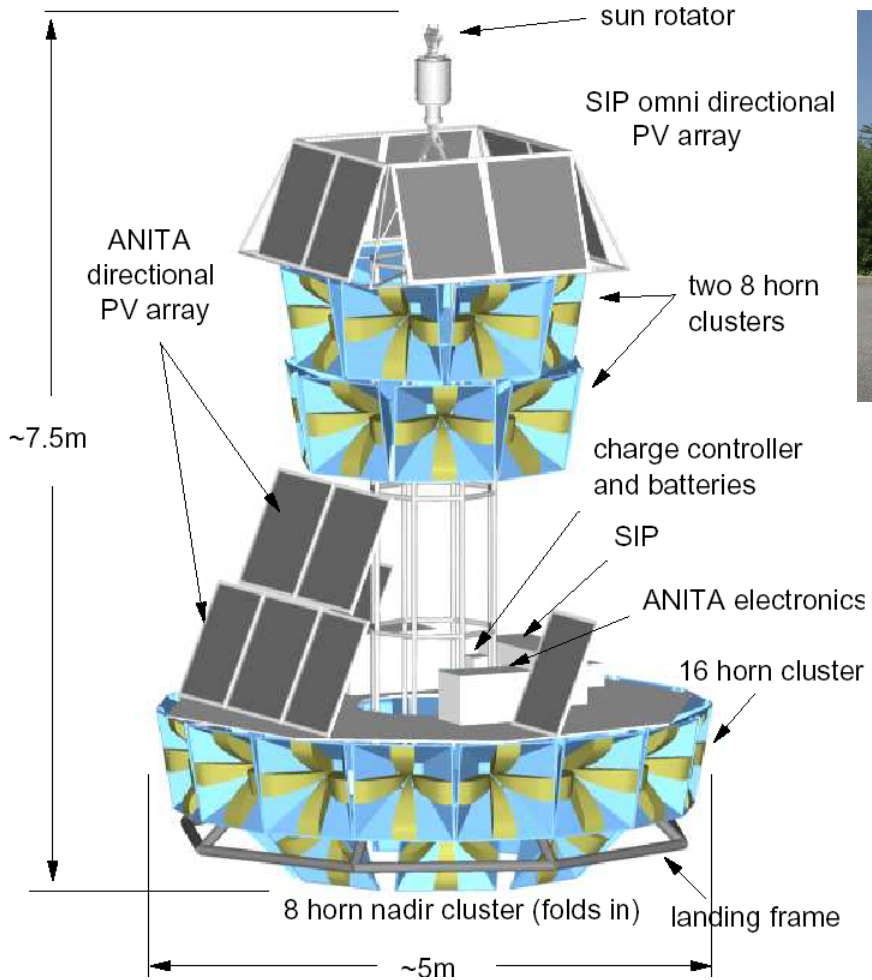


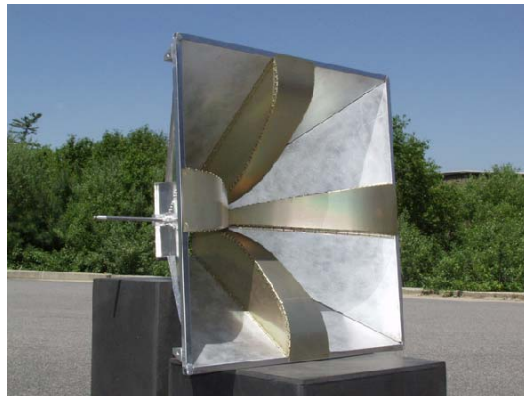
Effective "telescope" aperture:

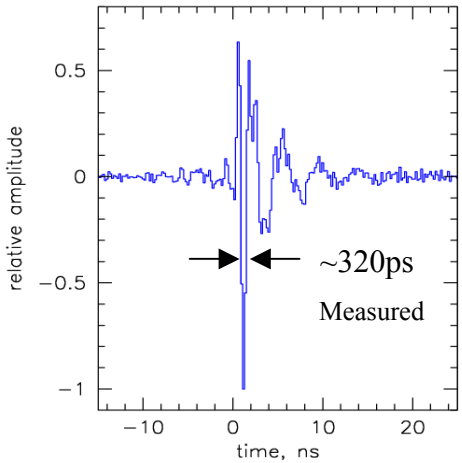
- ~250 km^3 sr @ $10^{18.5}$ eV
- ~10^4 @ km^3 sr @ $10^{19.5}$ eV

Flight Payload Design

A radio "feedhorn array" for the Antarctica Continent

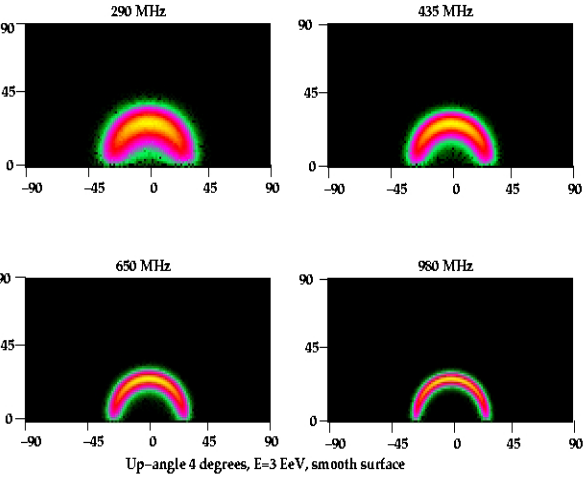


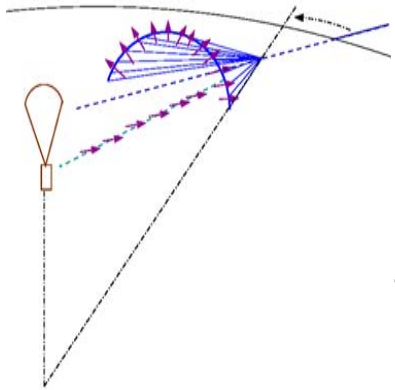


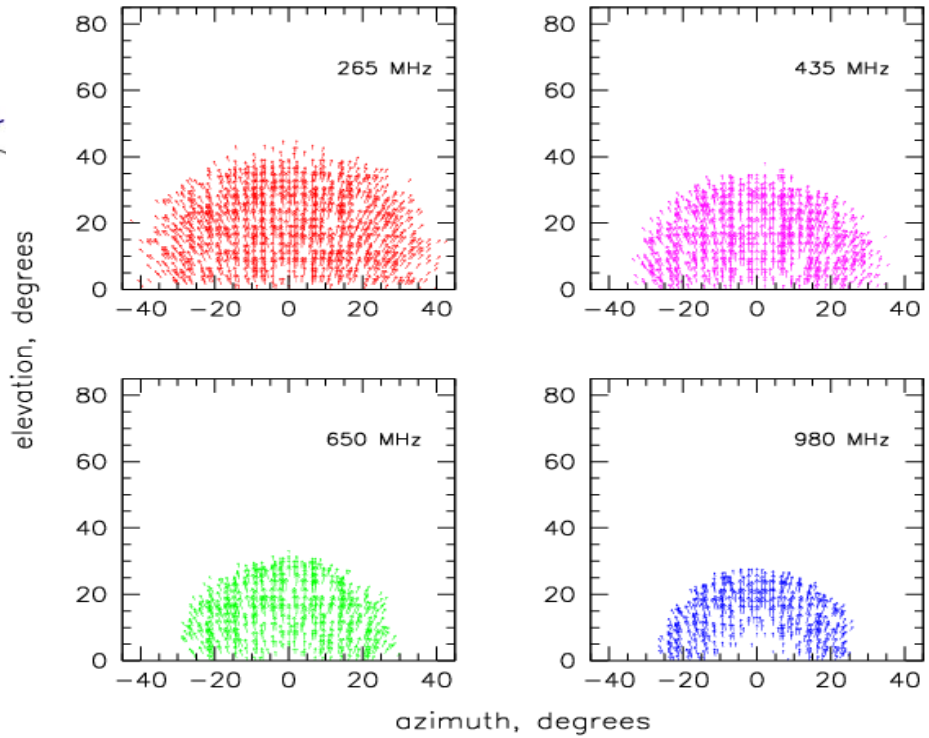


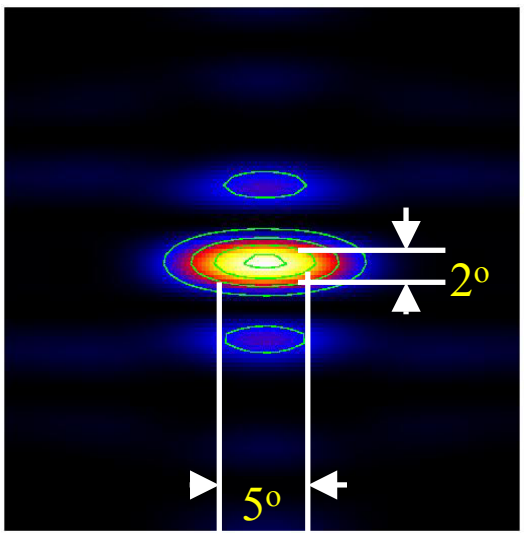
- Quad-ridged horn antennas provide superb impulse response & bandwidth
- Interferometry & beam gradiometry from multiple overlapped antenna measurements

ANITA as a neutrino telescope



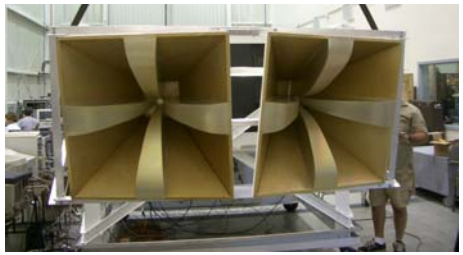


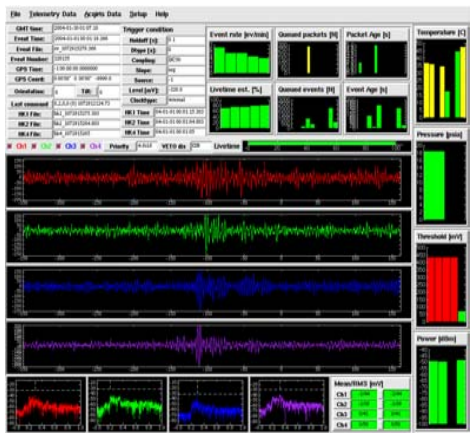




- Pulse-phase interferometer (150ps timing) gives intrinsic resolution of <1° elevation by ~1° azimuth for **arrival direction** of radio pulse
- **Neutrino direction** constrained to ~<2° in elevation by earth absorption, and by ~3-5° in azimuth by polarization angle

ANITA-lite Prototype flight 2004

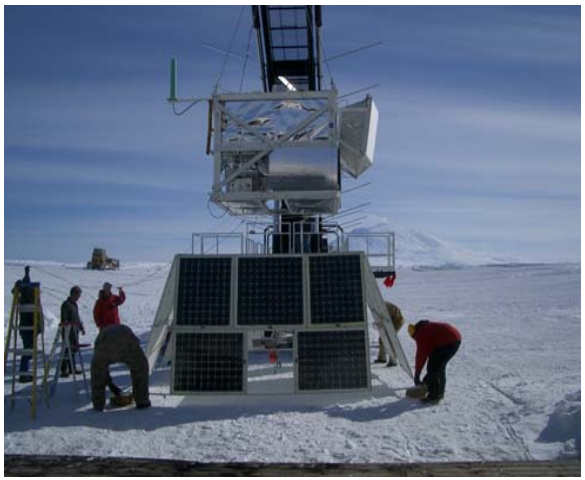


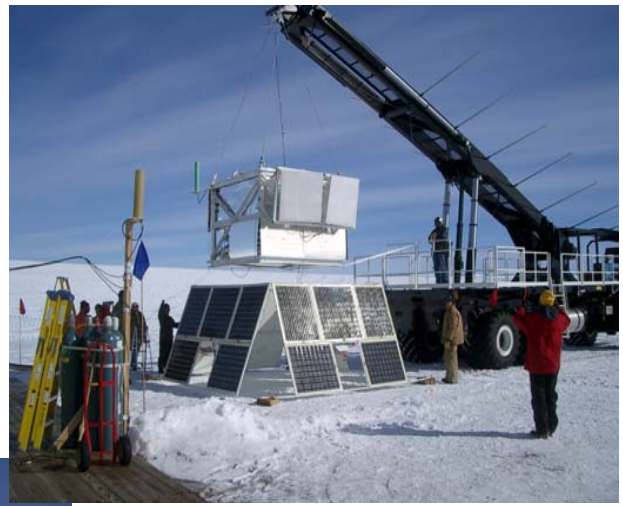


- Piggyback Mission of Opportunity on the 03-04 TIGER* flight, completed mid-January 04
- ANITA prototypes & off-the-shelf hardware used
  - 2 dual-pol. ANITA antennas w/ low-noise amps
  - 4 channels at 1 GHz RF bandwidth, 2 GHz sampling
- 18.4 days flight time, 40% net livetime due to slow (4sec per event) GPS time readout
- "Heartbeat" event rate of several per minute, with~100K events recorded:
  - payload generated EMI + thermal noise + calibration triggers + forced/timeout triggers

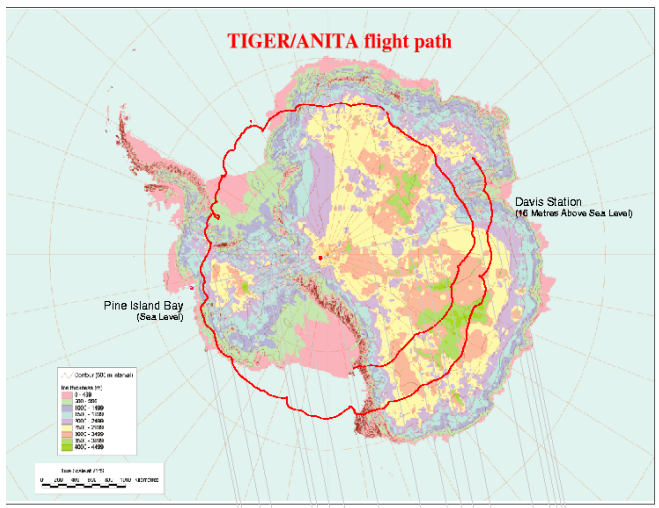
*Trans-Iron Galactic Element Recorder

TIGER/ANITA-lite launch

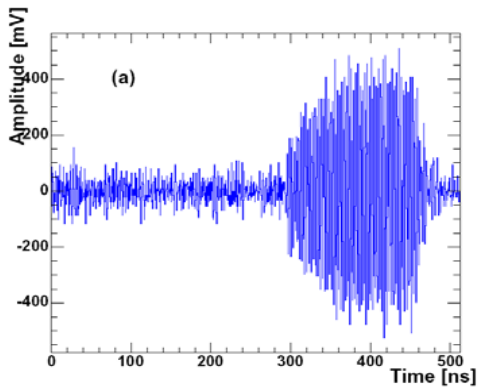


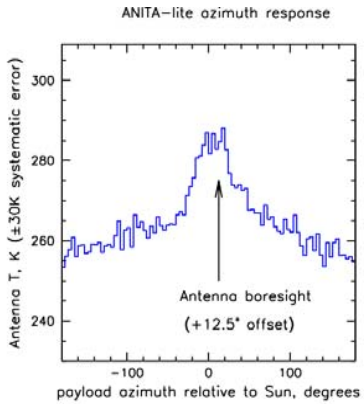


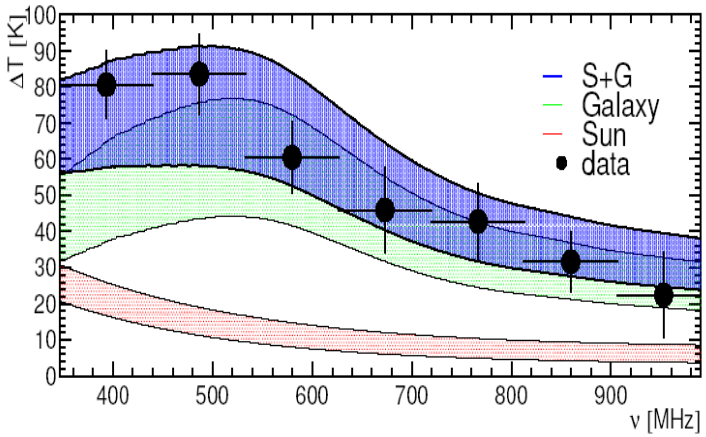
…& Landing


TIGER/ANITA flight path
Davis Station
(16 Metres Above Sea Level)
Pine Island Bay
(Sea Level)

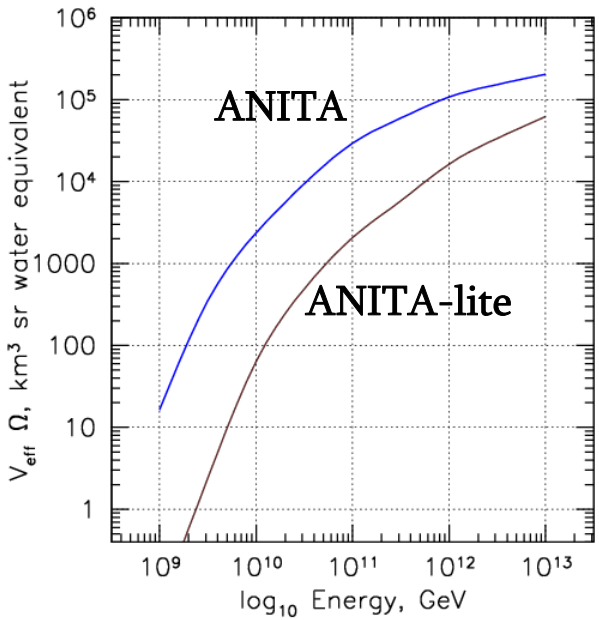
ANITA-lite sensitivity calibration



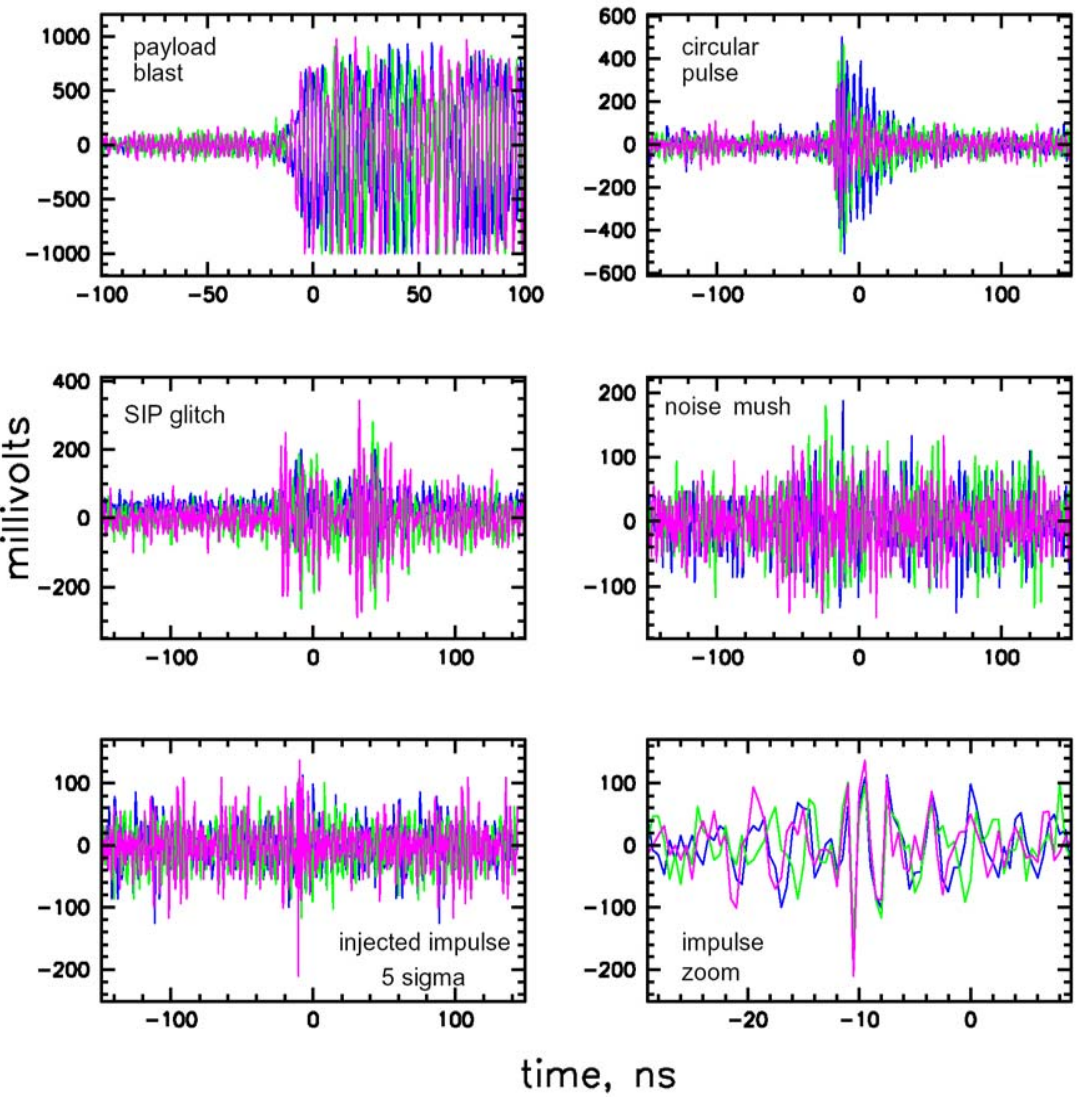




- Ground RF pulser used with GPS synch out to 200-300 km from McMurdo station
- Galactic Center & solar thermal & non-thermal RF emission provided real-time antenna sensitivity, along with onboard noise diodes for gain calibration
- Aperture estimate by Monte-Carlo using ice thickness data & balloon trajectory

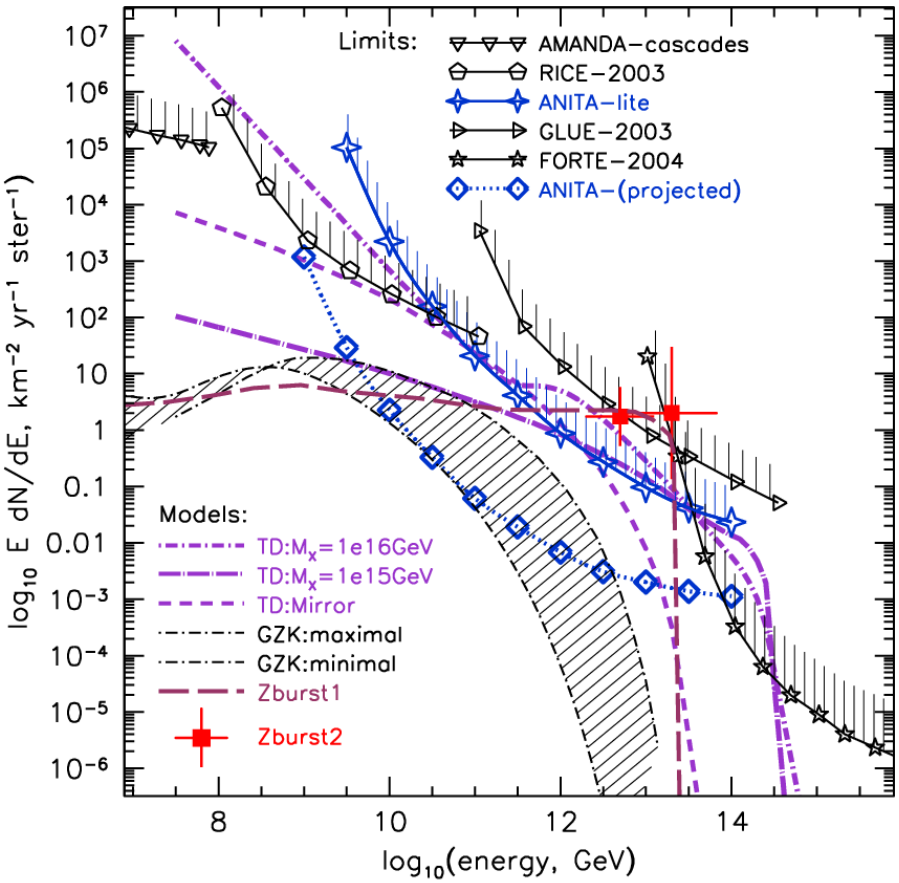


ANITA-lite impulse analysis



- **Dominated by payload local noise**
- **Circularly polarized impulses** (TDRSS relay turn-on?)
- **Glitches** from balloon support package (charge controller MOSFETS)
- **Injected Cherenkov signals** (overlain on actual thermal noise) used to test algorithm efficiency
- **Accidental rate**: 3-fold, 5 sigma:
  - Of order 1 per week, but still not phase coherent

Anita-lite & other limits & projections



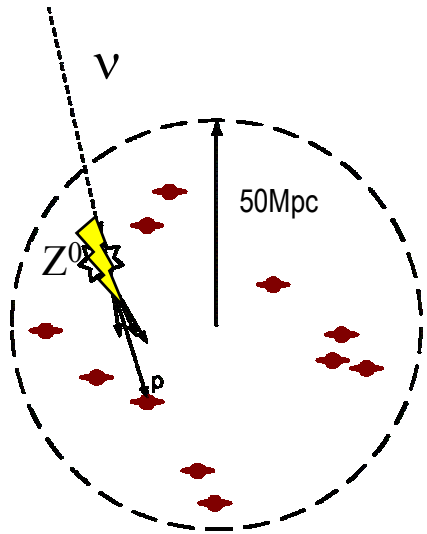
- **RICE** limits for 3500 hours livetime in embedded South Pole radio array
- **GLUE** limits ~120 hours livetime, Lunar regolith observations
- **FORTE** limits on 3 days of satellite observations of Greenland ice sheet

- **ANITA-lite**: 18.4 days of data, net 40% livetime with 60% analysis efficiency for detection
- Ice coverage & average depths included
- No candidates survive impulse cuts in 2 independent analyses (UH & UCI)
- Z-burst model ($\nu\nu$ annihilation --> UHECR) excluded:
  - we expect 6-50 events, see none
- Highest Toplogical defect models also excluded

- **ANITA projected sensitivity:**
  - ν_e ν_μ ν_τ included, full-mixing assumed
  - **1.5-2.5 orders of magnitude gain!**

The Z-burst model

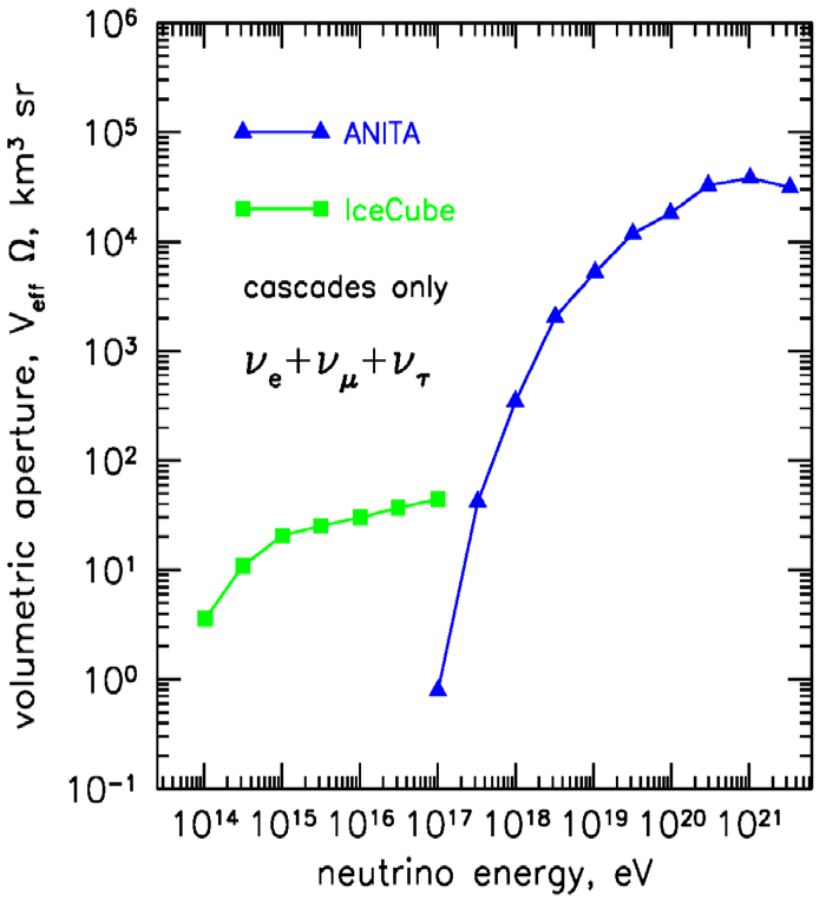
- Original idea, proposed as a method of Big-bang relic neutrino detection via resonant annihilation (T. Weiler PRL 1986):
  - 10^{23} eV $\nu + 1.9\text{K}\ \bar{\nu} \longrightarrow Z_0$ produces a dip in a cosmic neutrino source spectrum with a location dependent on the ν mass ,
  - *IF one has a source of 10^{23} eV neutrinos!*



- More recently: Z_0 decay into hadron secondaries gives 10^{20+} eV protons to explain any super-GZK particles, again
  - *IF there is an appropriate source of neutrinos at super-mega-GZK energies*
- (Many authors including Weiler have explored this revived version)

- The Z-burst proposal has the virtue of solving three completely unrelated (and very difficult) problems at once:
  - **relic neutrino detection AND super-GZK cosmic rays AND neutrino mass**
  - **==> " Nobel³ " physics…. ?**

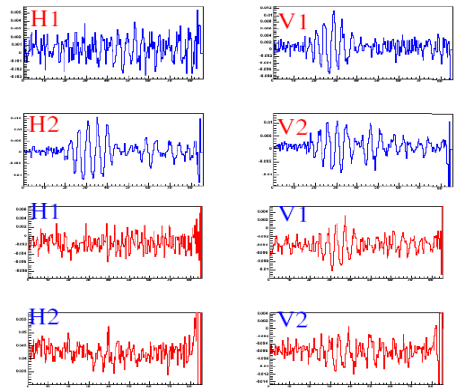
ANITA & IceCube



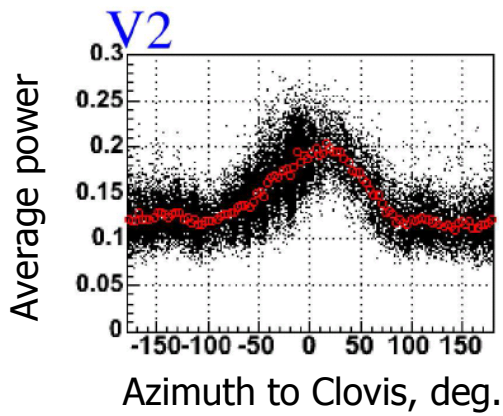
From D. Saltzberg 2005

- Different energy regime, very complementary
- IceCube designed for TeV to PeV sources, with some reach to 0.1 EeV energies, though saturated in effective volume
- ANITA "turns on" only for EeV-ZeV sources--GZK neutrinos

ANITA Engineering Flight, August 2005

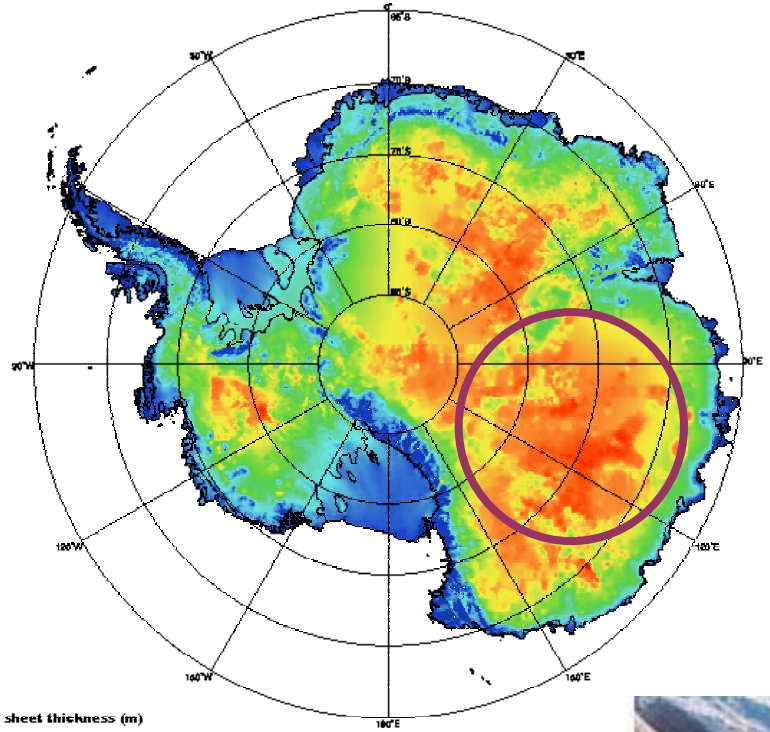


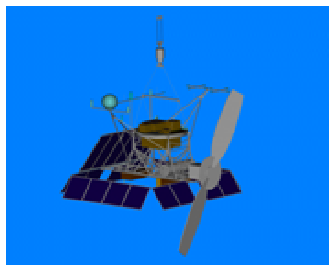
- August 29,2005, Ft. Sumner New Mexico
  - All subsystems represented (two dual-pol. antennas only, to limit landing damage)
  - 8 m tall Gondola performed perfectly
  - No science possible due to EMI (Cannon AFB in nearby Clovis), but waveform recording worked well
  - Full ANITA payload now cleared for Antarctica



For the future: Antarctic station-keeping payload?

- ANITA could greatly improve duty cycle if payload could keep station above <u>east Antarctica</u>
  - ~3-4 km ice depth, least anthropogenic activity
- Either tethered airship at ~80Kft (wind minimum) or station-keeping balloon possible
- With lightweighting of antenna arrays, other possibilities (eg. High altitude UAV aircraft) also possible





Summary

- Radio Cherenkov detection of cosmogenic neutrinos is well on the way toward 'first light' in 2006-2007
- ANITA-lite: a strong proof-of-concept for ANITA, with some physics thrown in as well
- Antarctica is an unmatched resource for physics and astrophysics…

  (Turn off the greenhouse gases please!)